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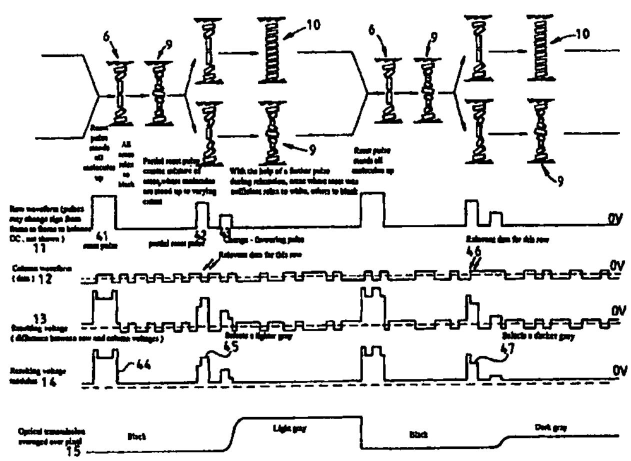

(57) Abstract

A liquid crystal device includes at least three different optical attenuation levels and includes a bistable twisted nematic liquid crystal cell having a first metastable state, which has a first degree of twist and is metastable in the absence of a substantial applied field, and a second metastable state, which has a second degree of twist different from the first degree of twist and is metastable in the absence of a substantial applied field. The device includes an address generator for applying across the cell a field having a waveform which includes a first portion for resetting the liquid crystal to a reset state having the first degree of twist, a second portion for allowing the liquid crystal to relax into a relaxed state having the second degree of twist and a third portion including any one of at least three different waveforms for selecting the at least three different optical attenuation level respectively. In at least one of the attenuation levels, a first portion of the liquid crystal of the cell is in the first metastable state and a second portion of the liquid crystal of the cell is in the second metastable state.

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DESCRIPTION

METHOD OF DRIVING A BISTABLE CHOLESTERIC LIQUID CRYSTAL DEVICE

TECHNICAL FIELD

The invention relates to a liquid crystal device.

BACKGROUND ART

The term "twist" as used herein is defined to mean the angle in the plane of a liquid crystal cell through which the liquid crystal director rotates from one surface of the cell to the other surface.

The bistable twisted nematic (BTN) effect is disclosed in EP 0 018 180, US 4 239 345 and "New Bistable Liquid Crystal Twist Cell", D.W. Berreman et al, J. Appl. Phys., 1981, volume 52(4), page 3032. Figure 1 of the accompanying drawings illustrates a simple example of the BTN mode of operation. A cholesteric (twisted nematic) material with a pitch of substantially twice the cell gap in a cell with parallel or antiparallel alignment directions adopts an initial state with a twist of 180°. In the antiparallel alignment, the 180° twist state has the disadvantage of being splayed. Accordingly, apart from

the initial stable state, two further metastable states which are free from splay but which have less favourable degrees of twist, namely 0° and 360°, can exist. These metastable states can be generated much more quickly than the 180° state and are the two states used in the BTN mode. In thin cells between crossed or orthogonal polarisers, the 360° twist state appears black whereas the 0° twist state, whose optic axis is oriented at 45° to the polariser directions, appears white.

The stable "twist-splay" state is illustrated at 1 in a liquid crystal cell with antiparallel alignment layers 2 and 3. An initial reset pulse 4 is applied across electrodes (not shown) between which the liquid crystal 5 and the alignment layers 2 and 3 are disposed. The reset pulse 4 has an amplitude and duration sufficient to cause a transition to the homeotropic state which is illustrated at 6 and in which the liquid crystal molecules 5 in the bulk of the layer (away from the immediate vicinity of the alignment layers 2 and 3) are oriented perpendicular to the cell surfaces as illustrated, for instance, by molecule 7.

One of two types of selective addressing pulse 8 is then

applied to the electrodes to select the desired state of the device. One type of selective addressing pulse causes the homeotropic state 6 to switch to the metastable black state which is illustrated at 9 and in which the liquid crystal has a 360° twist. This is the maximally attenuating or black state where the cell is disposed between orthogonal polarisers. The other type of addressing pulse 8 causes the liquid crystal to switch from the homeotropic state 6 to the metastable white state 10, in which there is 0° of twist and the cell appears minimally attenuating or white with the orthogonal polarisers. The prior art mentioned hereinbefore provides the selective addressing pulses 8 by reducing the voltage from the initial reset pulse 4 abruptly or gradually. However, other waveforms may also be used. For instance, EP 0 569 029 discloses addressing a BTN liquid crystal device (LCD) by a selection pulse of variable voltage following the initial reset pulse. JP H7-248485 discloses a technique for providing faster addressing by inserting a preset pulse between the initial reset pulse and the addressing pulse.

EP 0 579 247 discloses techniques for optimising the polariser and analyser positions to provide optimum

contrast in a BTN LCD.

"A Bistable Twisted Nematic (BTN) LCD Driven by a Passive Matrix Addressing", T. Nanaka et al, proceedings of Asia Display 1995, page 259 discloses a passively addressed black and white BTN panel.

EP 0 613 116 discloses a technique for providing short address times by optimising the position in time after the reset pulse of a short selection pulse. This is illustrated in Figure 2 of the accompanying drawings. The BTN LCD is arranged as a rectangular array of picture elements (pixels) to form a panel with row electrodes common to each row of pixels receiving strobe waveforms and column electrodes common to the pixels of each column receiving data signals. A typical strobe or row waveform is illustrated at 11, a typical data or column waveform is illustrated at 12, the resulting voltage across the liquid crystal layer is illustrated at 13 and the magnitude or modulus of the resulting voltage is illustrated at 14. The optical transmission of the cell is illustrated at 15.

The liquid crystal is shown in the metastable black state

9 at the start of the addressing interval illustrated in Figure 2. The reset pulse 4 resets the liquid crystal to the homeotropic state 6 and is followed by a select pulse 16. Simultaneously, the data waveform for selecting the desired state of the liquid crystal is applied to the column electrodes as illustrated at 17. This results in a voltage and hence electric field across the liquid crystal of an amplitude 18 such that the liquid crystal relaxes to the white metastable state 10.

During subsequent addressing of the pixel under consideration, a further reset pulse 4' resets the liquid crystal to the homeotropic state 6 and a further select pulse 16' cooperates with the appropriate data waveform 17' to produce a resulting pulse amplitude 18' which causes the liquid crystal to relax into the black metastable state 9.

A disadvantage of the known BTN LCDs is that, because it is a bistable mode, only black and white states can be addressed. In order to address intermediate grey levels, various techniques may be used. For instance, mixtures of black and white areas may be created within each pixel by subpixellation such that the subpixels are smaller

than the resolution of the eye. However, such an arrangement requires more driver circuitry and faster switching liquid crystal mixtures if the technique is not to be limited to relatively small low definition display panels. Also, greater construction accuracy is required.

Another known technique is to apply different voltages or voltage sequences to a pixel so as to provide different amounts of black and white areas. For instance, this may be achieved with non-uniform pixels where different areas of the pixel have different properties which require different switching voltages. This technique is known as "multi-threshold modulation" and again requires subpixellation implying additional fabrication steps and requiring greater construction accuracy. Thus, none of the known types of BTN LCD allow grey level addressing to be achieved without spatial or temporal multiplexing and the associated disadvantages in terms of increased addressing speed, increased constructional complexity, or both.

EP 0 234 624 discloses a super-twisted nematic (STN) LCD which is capable of displaying grey levels by multidomain techniques. The electro-optic (voltage/transmission)

characteristic of this device exhibits hysteresis. Different grey levels can be achieved by applying and maintaining across the liquid crystal cell electric fields of different magnitudes.

DISCLOSURE OF INVENTION

According to a first aspect of the invention, there is provided a liquid crystal device having at least three different optical attenuation levels and comprising a bistable twisted nematic liquid crystal cell having a first metastable state, which has a first degree of twist and is metastable in the absence of a substantial applied field, and a second metastable state, which has a second degree of twist different from the first degree of twist and is metastable in the absence of a substantial applied field. The device includes an address generator for applying across the cell a field having a waveform including: a first portion for resetting the liquid crystal to a reset state having the first degree of twist; a second portion for allowing the liquid crystal to relax into a relaxed state having the second degree of twist; and a third portion including any one of at least three different waveforms for selecting the at least three different optical attenuation levels, respectively,

wherein, in at least one of the attenuation levels, a first portion of the liquid crystal of the cell is in the first metastable state and a second portion of the liquid crystal of the cell is in the second metastable state.

According to another aspect of the invention, the second portion of the waveform may comprise a space, i.e.: may be of a sufficiently low magnitude to allow relaxation.

According to another aspect of the invention, the relaxed state may be the second metastable state.

According to still another aspect of the invention, the at least three different optical attenuation levels may include a maximum attenuation level, a minimum attenuation level and at least one intermediate attenuation level.

According to yet another aspect of the invention, at least one of the first and third portions may include at least one pulse. The at least one pulse may include a monopolar pulse. The at least one pulse may comprise a bipolar pulse. Each bipolar pulse may include first and second subpulses of substantially equal amplitude and

opposite polarity.

According to still yet another aspect of the invention, the third portion may include a first part and a second part. The first part may comprise first and second pulses. The second pulse may be spaced from the first pulse. The amplitude of the first pulse may be less than the amplitude of the second pulse. The second part may comprise a plurality of pulses of progressively decreasing amplitude. The pulses of the second part may be contiguous.

According to yet another aspect of the present invention, the address generator may include a data signal generator and a strobe signal generator. The cell may comprise a liquid crystal layer disposed between a plurality of strobe electrodes for receiving strobe signals from the strobe signal generator and a plurality of data electrodes for receiving data signals from the data signal generator, the data electrodes intersecting the strobe electrodes to define picture elements. The data signal generator may be arranged to supply to the data electrodes data signals whose amplitudes are less than the Fredericksz transition voltages of the first and second

metastable states. The liquid crystal may have an initial stable state and the amplitudes of the data signals may be less than the Fredericksz transition voltage of the initial stable state. All of the data signals may include pulses of the same amplitude. All of the data signals may include symmetrical bipolar pulses. All of the data signals may include monopolar pulses. All of the data signals may be of the same root mean square voltage. The data signals for selecting different ones of the optical attenuation levels may have different pulse widths.

According to still another aspect of the present invention, the amplitude of the strobe signals may be greater than the Fredericksz transition of the less twisted one of the first and second metastable states. The amplitude of the strobe signals may be less than four times the Fredericksz transition of the less twisted one of the first and second metastable states.

According to yet still another aspect of the present invention, the liquid crystal of the cell may be disposed between first and second polarisers. The first and second polarisers may be linear polarisers with

polarising directions oriented substantially orthogonally. The polarising directions may be oriented at between 80° and 100° to each other.

According to still another aspect of the present invention, the liquid crystal of the cell may be disposed between first and second alignment layers for providing substantially antiparallel alignment oriented substantially at 45° to the polarising directions. The antiparallel alignment may be oriented at between 40° and 50° to the polarising directions. The first and second alignment layers may have first and second alignment directions oriented at an included angle of between 135° and 225°. The included angle may be between 170° and 190°. The included angle may be between 175° and 185°. The included angle may be between 178° and 182°.

According to yet another aspect of the present invention, each of the first and second alignment layers may be arranged to provide a pretilt of between 1° and 25°. The pretilt may be between 3° and 15°. The pretilt may be between 5° and 10°.

According to still another aspect of the invention, the

liquid crystal of the cell may have a thickness of between 1 and 3 micrometers.

According to still another aspect of the invention, $\Delta n \cdot d$ may be between 0.1 and 0.3 micrometers, where d is the thickness of the liquid crystal of the cell, $\Delta n = ne - no$, and ne and no are the extraordinary and ordinary refractive indices, respectively, of the liquid crystal in the second metastable state.

According to another aspect of the invention, the difference between the twists of the liquid crystal layer in the first and second metastable states may be substantially equal to 360°. The liquid crystal layer may have twists substantially equal to 0° and 360° in the first and second metastable states, respectively. The liquid crystal layer twist in each of the first and second metastable states may differ from that in an initial stable state by substantially 180°.

According to yet another aspect of the invention, the ratio of the thickness to the bulk pitch of the liquid crystal of the cell may be between 0.2 and 1.2. The ratio may be between 0.5 and 0.95. The ratio may be

between 0.6 and 0.9.

According to still another aspect of the invention, the device may include a matrix of rows and columns of picture elements, the address generator being arranged to supply each frame of image data as n consecutive subframes, where n is an integer greater than one, such that each ith subframe, where i is an integer such that $0<i\leq n$, comprises the $(i+n\cdot m)$th rows, where m is a non-negative integer.

It is thus possible to achieve grey level addressing of BTN LCDs without requiring special construction of the LCDs and without requiring the use of faster switching liquid crystal materials. The disadvantages associated with subdividing pixels or using pixels of nonuniform geometry are avoided and it is possible to provide a relatively cheap display having good viewing angle and speed while avoiding difficulties associated with other types of liquid crystals, such as active matrix twisted nematic LCDs, supertwisted nematic LCDs, ferroelectric and antiferroelectric LCDs.

The invention will be further described, by way of

example, with reference to the accompanying drawings, in which:

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a schematic diagram illustrating operation of a known type of BTN LCD;

Figure 2 is a diagram illustrating waveforms and liquid crystal modes of a known type of BTN LCD;

Figure 3 is a schematic diagram of a passively addressed BTN LCD constituting an embodiment of the invention;

Figure 4 is a diagrammatic cross sectional view of the device of Figure 3;

Figure 5 illustrates the orientation of various optical components in the device of Figure 3;

Figure 6 illustrates various waveforms for use in and the resulting performance of the device of Figure 3;

Figure 7 illustrates diagrammatically known types of addressing waveforms;

Figure 8 illustrates diagrammatically various types of waveforms which may be used in the device of Figure 3;

Figure 9 illustrates another set of waveforms for use in and the resulting optical performance of the device of Figure 3;

Figure 10 illustrates a further set of waveforms for use in the device of Figure 3; and

Figure 11 shows microscope photographs illustrating the performance of the device of Figure 3 using the waveforms illustrated in Figure 9.

BEST MODE FOR CARRYING OUT THE INVENTION

Like reference numerals refer to like parts throughout the drawings.

Figure 3 illustrates a passive matrix BTN LCD constituting an embodiment of the invention. The device comprises a waveform generator, illustrated as a data signal generator 20 and a strobe signal generator 21 for supplying addressing waveforms to a rectangular matrix of pixels. The data and strobe signal generators 20 and 21

have inputs connected to a timing input 22 for receiving timing signals. The data signal generator 20 has a data input 23 for receiving data to be displayed.

The data signal generator is connected to n column electrodes 24 whereas the strobe signal generator 21 is connected to m row electrodes 25. Each column electrode 24 is common to the pixels of that column whereas each row electrode 25 is common to the pixels of that row. The pixels are defined at intersections between the column and row electrodes where a column electrode overlaps a row electrode, for instance as indicated at 26.

The data signal generator 20 is arranged to supply data signals Vd1,..,Vdn simultaneously to the n column electrodes 24 so as to refresh the pixels a row at a time. The strobe signal generator 21 is arranged to supply strobe signals Vs1,...,Vsm to the m row electrodes 25 one at a time in a repeating sequence so as to strobe the new image data a row at a time into the pixels.

Figure 4 is a diagrammatic cross sectional view illustrating the construction of the BTN LCD of Figure 3 in

the form of a transmissive display, although a reflective display could also be provided. The device comprises a polariser 30 fixed to the exterior surface of a transparent substrate 31, for example made of glass. The substrate 31 carries the row electrodes 25 made of a transparent conductor such as indium tin oxide (ITO) and an alignment layer 3, for instance comprising rubbed polyimide. A polariser 32 is fixed to the external surface of another transparent substrate 33, for instance made of glass. The substrate 33 carries on its internal surface the column electrodes 24 which are made of a transparent conductor, such as ITO, and an alignment layer 2, for instance comprising rubbed polyimide. In order to define a liquid crystal layer, the device is assembled with the alignment layers 2 and 3 facing each other and spaced apart by spacers 34. The resulting gap is filled with a cholesteric liquid crystal 5 to form a layer which is sealed in any suitable way.

The polariser and alignment directions of the polarisers 30 and 32 and the alignment layers 2 and 3 are illustrated in Figure 5. In particular, the polarising directions of the polarisers 30 and 32 are illustrated at 35 and 36, respectively, whereas the surface alignment directions of

the alignment layers 2 and 3 are illustrated at 37. The polarisation directions 36 and 35 are substantially orthogonal whereas the alignment directions 37 are antiparallel and oriented at substantially 45° to the polarising directions 35 and 36. The liquid crystal 5 has substantially twisted and substantially untwisted metastable states. The twisted state is illustrated by the orientation of liquid crystal molecules shown at 38 and, in this state has a twist of substantially 360°. The untwisted state is illustrated at 39 with all the molecules aligned in the directions 37. In the twisted metastable state, light 40 is polarised in the direction 35 by the polariser 30 and its polarisation is substantially unaffected by passage through the liquid crystal 5. The orthogonal polarisation 36 results in absorption of the light 40 so that the pixel appears black or opaque.

In the case of the untwisted metastable state shown at 39, the birefringence of the liquid crystal 5 is such that the polarisation of light from the polariser 30 is rotated by substantially 90° so as to be aligned with the polarisation direction 36. The pixel therefore appears white or transmissive.

Figure 6 illustrates waveform diagrams of the data and strobe signals supplied by the data and strobe signal generators 20 and 21. The strobe or row waveform 11 comprises a first portion followed by a second portion which, in turn, is followed by a third portion comprising first and second parts. The first portion comprises a reset pulse 41. The second portion comprises a space or reset period. The first part of the third portion comprises what is termed as a partial reset pulse 42. The second part of the third portion comprises what is termed as a change-favouring pulse 43.

The column or data waveform comprises bipolar pulses of constant amplitude but of varying width so as to select the desired grey level of the pixels. The data pulses are bipolar and are such as to have no net DC component. The strobe pulses are monopolar and their polarities may be changed periodically, for instance from frame to frame, so as to preserve DC balance and avoid degradation of the liquid crystal 5.

The resulting waveforms appearing across the liquid crystal are shown at 13 and the amplitude or modulus of the waveform is shown at 14.

In order to refresh a row of pixels, during the first portion of the strobe signal waveform and hence of the waveform of the field across the pixels of the rows, the reset pulse 41 is supplied by the strobe signal generator 21 to the appropriate row electrode 25 while other rows are being refreshed. The modulus of the resultant voltage shown at 44 is greater than the Fredericksz transition voltage so that the liquid crystal is reset to the homeotropic state 6 having zero twist. During the second portion of the strobe signal waveform and hence of the pixel field waveform, the pixels of the row being refreshed receive only the data signal waveforms. These are of sufficiently small amplitude to allow the liquid crystal to relax to a state having 360° of twist, which is believed to be the twisted or black metastable state 9 but which may be or include a partially homeotropic state having a 360° twist.

In the third portion of the strobe signal waveform and hence of the pixel field waveform, a partial reset pulse 42 is applied to the row electrode 25 and, together with the data waveform, supplies a voltage whose modulus 45 is intended to select a relatively light grey. In particular, the height and width of the pulse 42 are selected so

as to achieve what is presently believed to be partial blanking or resetting. The degree of blanking or resetting therefore varies in different areas of the pixel. This variation may be caused by director fluctuations in the cholesteric or by inhomogeneous flow during the Fredericksz transition. It is believed that, in areas where blanking caused by the pulse 42 is sufficient, the non-twisted homeotropic or prewhite state is created whereas, in areas where the partial reset pulse 42 has less effect, the liquid crystal is blanked into a near-homeotropic state of 360° of twist representing a preblack state. The relative abundance of prewhite and preblack domains is determined by the data voltage applied simultaneously with the partial reset pulse 42.

The change-favouring pulse 43 is then applied and, it is presently believed, acts as a "kick white" pulse to create white in the areas in the prewhite state. Areas in the preblack state are not affected by the pulse 43 and relax to the black state. The change-favouring pulse 43 is chosen such that the data voltage which is simultaneously applied does subsequently not affect which final state is selected.

An alternative addressing technique differs from that described hereinbefore in that the pulses 42 and 43 are chosen in such a way that the resulting transmission is substantially determined by the data voltage supplied during the pulse 43. The pulse 43 is believed to contribute to the Fredericksz transition begun during the pulse 42 and thus influence the ratio of prewhite and preblack areas. As described hereinbefore, the pulse 43 is also believed to support the relaxation of prewhite areas to the white relaxed state.

The local differences in the degree of blanking are believed to be caused by thermal fluctuations in the cholesteric liquid crystal or by voltage-change induced dynamic inhomogeneities or both. In particular, during resetting and relaxing of the liquid crystal, the liquid crystal molecules cannot all move in the same way and so they temporarily acquire different orientations in different locations. By varying the modulus 45 of the waveform of the field applied to the liquid crystal, analogue selection of grey level can be achieved. For instance, the data waveform shown at 46 results in a waveform whose modulus 47 selects or addresses a darker grey level than that addressed by the modulus 45.

Figure 7 illustrates diagrammatically the type of waveforms used in the known addressing arrangement described hereinbefore whereas Figure 8 illustrates diagrammatically various types of waveform which may be used in accordance with the present invention. Figure 7 illustrates at (a) the type of waveform disclosed in EP 0 018 180 in which the reset pulse 41 decays rapidly as shown at 50 to address black or more slowly as shown at 51 to address white.

Figure 7 illustrates at (b) and (c) two types of waveform as disclosed in EP 0 569 029. The reset pulse 41 is followed by a variable pulse 52 which is contiguous in (b) and spaced from the reset pulse 41 in (c).

Figure 8 shows at (a) the resetting pulse 41 followed by a space followed by the partial reset pulse 42 and the change-favouring pulse 43. In (a) the pulses 42 and 43 are spaced apart in time.

Variations of this waveform structure within the scope of the invention are illustrated at (b) to (i) in Figure 8. In particular, the pulses 42 and 43 may be spaced from each other in time or may be contiguous in time and each

may comprise a combination of pulses. For instance, as shown at (b) and (c), the partial reset pulse 42 may be divided into two parts 42a and 42b, which may be contiguous as shown at (b) or may be spaced in time as shown at (c). The first part 42a is of lower amplitude than the second part 42b and the second part 42b is shaped so that only data supplied during the first part 42a influences the grey level selection.

The single change-favouring pulse 43 may comprise a series of pulses of decreasing amplitude as shown at (d), (e) and (f) in combination with the pulses 42, 42a, 42b shown at (a), (b) and (c), respectively. The partial reset pulse 42 and the change-favouring pulse 43 may not be clearly distinguishable in the waveform, for instance as illustrated at (d) to (i).

Figure 9 illustrates waveform diagrams and optical transmission for a waveform of the type shown in Figure 8 at (c). The column waveform 12(a) cooperates with the first part 42a of the bipolar partial reset pulse 42 to cause substantially the whole pixel to be switched to the transparent or white state as shown at 15(a). The column or data waveform shown at 12(b) controls addressing of an

intermediate or grey level as illustrated by the transmission curve 15(b). The column or data waveform illustrated at 12(c) results in switching of substantially the whole pixel to black as illustrated by 15(c).

The performance illustrated in Figure 9 is achieved with a device of the type illustrated in Figures 3 to 5 having a liquid crystal thickness of 2 micrometers and using a liquid crystal comprising a nematic liquid crystal mixture ZLI-4792 doped with a chiral dopant R-1011 to a cholesteric pitch of 3 micrometers (both materials are available from Merck). The alignment layers 2 and 3 comprise antiparallel polyimide with a pretilt of approximately 5°. The row waveform 11 comprises a reset pulse 41 having a duration of 3 milliseconds and an amplitude of 37 volts. This is followed by a zero volt space of 11 milliseconds followed by the bipolar pulse 42a having a duration of 0.25 milliseconds and an amplitude of 4.5 volts. This is followed by a gap of 0.25 milliseconds and the part 42b having a duration of 0.25 milliseconds and an amplitude of 35 volts. This is followed by a gap of 0.5 milliseconds and the pulse 43 having a duration of 0.25 milliseconds and an amplitude of 9 volts. This is followed by a gap of 30 milliseconds before the waveform

is repeated. The column waveform comprises bipolar pulses with an amplitude of 2.5 volts and being based on a pulse duration of 25 microseconds.

Figure 10 illustrates data waveforms for providing ten grey levels including black and white for a display of the type illustrated in Figures 3 to 5. In this case, the polarising directions 35 and 36 are at 4° and 86° with the alignment direction 37 at 45°. The alignment layers 2 and 3 comprise antiparallel polyimide arranged to provide a pretilt of approximately 7°, such as RN 715 available from Merck. The liquid crystal layer has a thickness of 1.4 micrometers and comprises a nematic liquid crystal mixture ZLI-4792 doped with a chiral dopant R-1011 comprising approximately 1.3% by weight. The row waveform 11 comprises the bipolar reset pulse 41 having a duration of 3 milliseconds and an amplitude of 30 volts followed by a gap of 4.2 milliseconds. The monopolar pulse 42 has a duration of 88 microseconds and an amplitude of 17.1 volts and is followed by a gap of 0.204 milliseconds. This is followed by the bipolar pulse train 43 having a duration of 1 millisecond and an amplitude of 5.3 volts. There is then a gap of 24.308 milliseconds before the row waveform repeats. The

polarity of the pulse 41 changes halfway through the duration of the pulse 41 whereas the pulse 42 changes polarity at every repeat. The pulse train 43 comprises individual pulses having a width of 8 microseconds offset by 4 microseconds from polarity changes in the column waveform 12.

The column waveform comprises bipolar pulses of length 8 microseconds and of amplitude 1.7 volts.

The specific data pulse waveforms required to achieve the ten grey levels (numbered 1 to 10 against the waveforms) from black to white are shown synchronised with the partial reset pulse 42.

Figure 11 shows at (a), (b) and (c) results obtained using the device described hereinbefore with the waveforms illustrated in Figure 9. In particular, the black corresponding to the transmission 15(c) is shown at (c) in Figure 11. The white obtained by the column waveform 12(a) as illustrated by the transmission curve 15(a) is illustrated at (a) in Figure 11. Similarly, the grey level indicated by the transmission curve 15(b) is shown at (b) in Figure 11. Thus, it is possible to

maintain a good contrast ratio between black and white and provide an intermediate grey level which may be well-distinguished from both black and white.

INDUSTRIAL APPLICABILITY

According to the invention, it is thus possible to achieve grey level addressing of BTN LCDs without requiring special construction of the LCDs and without requiring the use of faster switching liquid crystal materials. The disadvantages associated with subdividing pixels or using pixels of nonuniform geometry are avoided and it is possible to provide a relatively cheap display having good viewing angle and speed while avoiding difficulties associated with other types of liquid crystals, such as active matrix twisted nematic LCDs, supertwisted nematic LCDs, ferroelectric and antiferroelectric LCDs.

CLAIMS

1. A liquid crystal device having at least three different optical attenuation levels and comprising a bistable twisted nematic liquid crystal cell having a first metastable state, which has a first degree of twist and is metastable in the absence of a substantial applied field, and a second metastable state, which has a second degree of twist different from the first degree of twist and is metastable in the absence of a substantial applied field, the device comprising:

an address generator for applying across the cell a field having a waveform including:

a first portion for resetting the liquid crystal to a reset state having the first degree of twist; a second portion for allowing the liquid crystal to relax into a relaxed state having the second degree of twist; and

a third portion comprising any one of at least three different waveforms for selecting the at least three different optical attenuation levels, respectively, wherein, in at least one of the attenuation levels, a first portion of the liquid crystal is in the first metastable state and a second portion of the liquid

crystal is in the second metastable state.

2. A device as claimed in Claim 1, wherein the second portion of the waveform comprises a space.

3. A device as claimed in Claim 1, wherein the relaxed state is the second metastable state.

4. A device as claimed in claim 1, wherein the at least three different optical attenuation levels comprise a maximum attenuation level, a minimum attenuation level and at least one intermediate attenuation level.

5. A device as claimed in claim 1, wherein at least one of the first and third portions comprises at least one pulse.

6. A device as claimed in Claim 5, wherein the at least one pulse comprises a monopolar pulse.

7. A device as claimed in Claim 5, wherein the at least one pulse comprises a bipolar pulse.

8. A device as claimed in Claim 7, wherein each bipolar

pulse comprises first and second subpulses of substantially equal amplitude and opposite polarity.

9. A device as claimed in claim 1, wherein the third portion comprises a first part and a second part.

10. A device as claimed in Claim 9, wherein the first part comprises first and second pulses.

11. A device as claimed in Claim 10, wherein the second pulse is spaced from the first pulse.

12. A device as claimed in Claim 10, wherein the amplitude of the first pulse is less than the amplitude of the second pulse.

13. A device as claimed in Claim 9, wherein the second part comprises a plurality of pulses of progressively decreasing amplitude.

14. A device as claimed in Claim 13, wherein the pulses of the second part are contiguous.

15. A device as claimed in claim 1, wherein the

address generator comprises a data signal generator and a strobe signal generator.

16. A device as claimed in Claim 15, wherein the cell comprises a liquid crystal layer disposed between a plurality of strobe electrodes for receiving strobe signals from the strobe signal generator and a plurality of data electrodes for receiving data signals from the data signal generator, the data electrodes intersecting the strobe electrodes to define picture elements.

17. A device as claimed in Claim 16, wherein the data signal generator is arranged to supply to the data electrodes data signals whose amplitudes are less than the Fredericksz transition voltages of the first and second metastable states.

18. A device as claimed in Claim 17, wherein the liquid crystal has an initial stable state and the amplitudes of the data signals are less than the Fredericksz transition voltage of the initial stable state.

19. A device as claimed in Claim 16, wherein all of the data signals comprise pulses of the same amplitude.

20. A device as claimed in Claim 16, wherein all of the data signals comprise symmetrical bipolar pulses.

21. A device as claimed in Claim 16, wherein all of the data signals comprise monopolar pulses.

22. A device as claimed in Claim 16, wherein all of the data signals are of the same root mean square voltage.

23. A device as claimed in Claim 19, wherein the data signals for selecting different ones of the optical attenuation levels have different pulse widths.

24. A device as claimed in Claim 16, wherein the amplitude of the strobe signals is greater than the Fredericksz transition of the less twisted one of the first and second metastable states.

25. A device as claimed in Claim 24, wherein the amplitude of the strobe signals is less than four times the Fredericksz transition of the less twisted one of the first and second metastable states.

26. A device as claimed in Claim 1, wherein the liquid crystal of the cell is disposed between first and second polarisers.

27. A device as claimed in Claim 26, wherein the first and second polarisers are linear polarisers with polarising directions oriented substantially orthogonally.

28. A device as claimed in Claim 27, wherein the polarising directions are oriented at between 80° and 100° to each other.

29. A device as claimed in Claim 27, wherein the liquid crystal of the cell is disposed between first and second alignment layers for providing substantially antiparallel alignment oriented substantially at 45° to the polarising directions.

30. A device as claimed in Claim 29, wherein the antiparallel alignment is oriented at between 40° and 50° to the polarising directions.

31. A device as claimed in Claim 29, wherein the

first and second alignment layers have first and second alignment directions oriented at an included angle of between 135° and 225°.

32. A device as claimed in Claim 31, wherein the included angle is between 170° and 190°.

33. A device as claimed in Claim 32, wherein the included angle is between 175° and 185°.

34. A device as claimed in Claim 33, wherein the included angle is between 178° and 182°.

35. A device as claimed Claim 29, wherein each of the first and second alignment layers is arranged to provide a pretilt of between 1° and 25°.

36. A device as claimed in Claim 35, wherein the pretilt is between 3° and 15°.

37. A device as claimed in Claim 36, wherein the pretilt is between 5° and 10°.

38. A device as claimed in Claim 1, wherein the

liquid crystal of the cell has a thickness of between 1 and 3 micrometers.

39. A device as claimed in Claim 1, wherein $\Delta n \cdot d$ is between 0.1 and 0.3 micrometers, where d is the thickness of the liquid crystal of the cell, $\Delta n = ne - no$, and ne and no are the extraordinary and ordinary refractive indices, respectively, of the liquid crystal in the second metastable state.

40. A device as claimed in Claim 1, wherein the difference between the twists of the liquid crystal layer in the first and second metastable states is substantially equal to 360°.

41. A device as claimed in Claim 40, wherein the liquid crystal layer has twists substantially equal to 0° and 360° in the first and second metastable states, respectively.

42. A device as claimed in Claim 40, wherein the liquid crystal layer twist in each of the first and second metastable states differs from that in an initial stable state by substantially 180°.

43. A device as claimed in Claim 1, wherein the ratio of the thickness to the bulk pitch of the liquid crystal of the cell is between 0.2 and 1.2.

44. A device as claimed in Claim 43, wherein the ratio is between 0.5 and 0.95.

45. A device as claimed in Claim 44, wherein the ratio is between 0.6 and 0.9.

46. A device as claimed in Claim 1, wherein a matrix of rows and columns of picture elements, the address generator being arranged to supply each frame of image data as n consecutive subframes, where n is an integer greater than one, such that each ith subframe, where i is an integer such that $0<i\leq n$, comprises the $(i+n\cdot m)$th rows, where m is a non-negative integer.

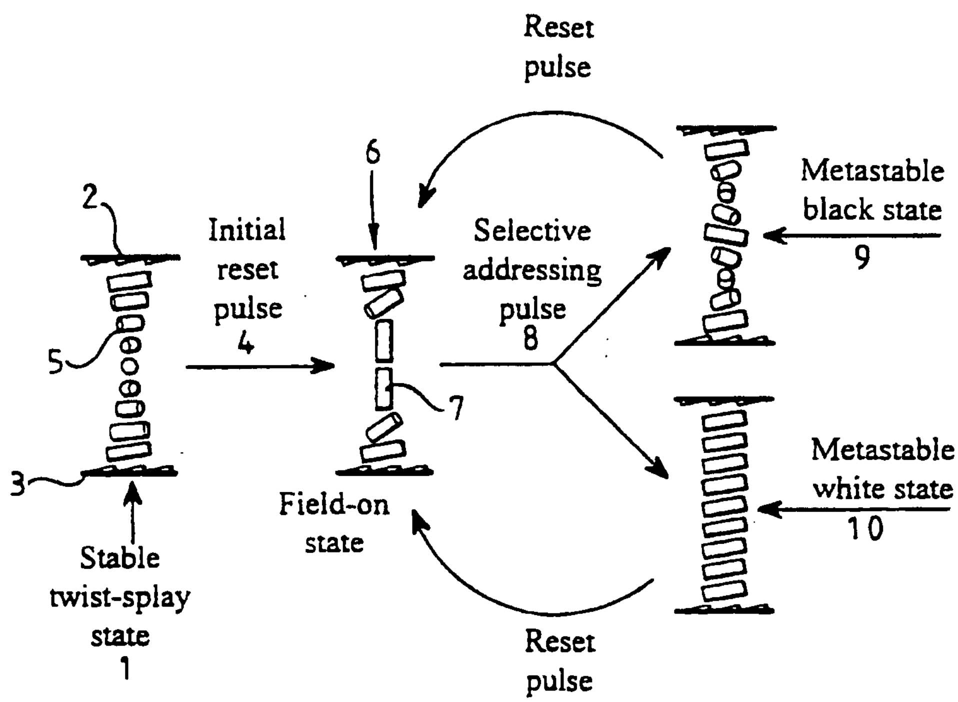

Reset
pulse
6
2
Initial
reset
pulse
4
Selective
addressing
pulse
8
Metastable
black state
9
5
7
3
Metastable
white state
10
Field-on
state
Stable
twist-splay
state
1
Reset
pulse

FIG 1

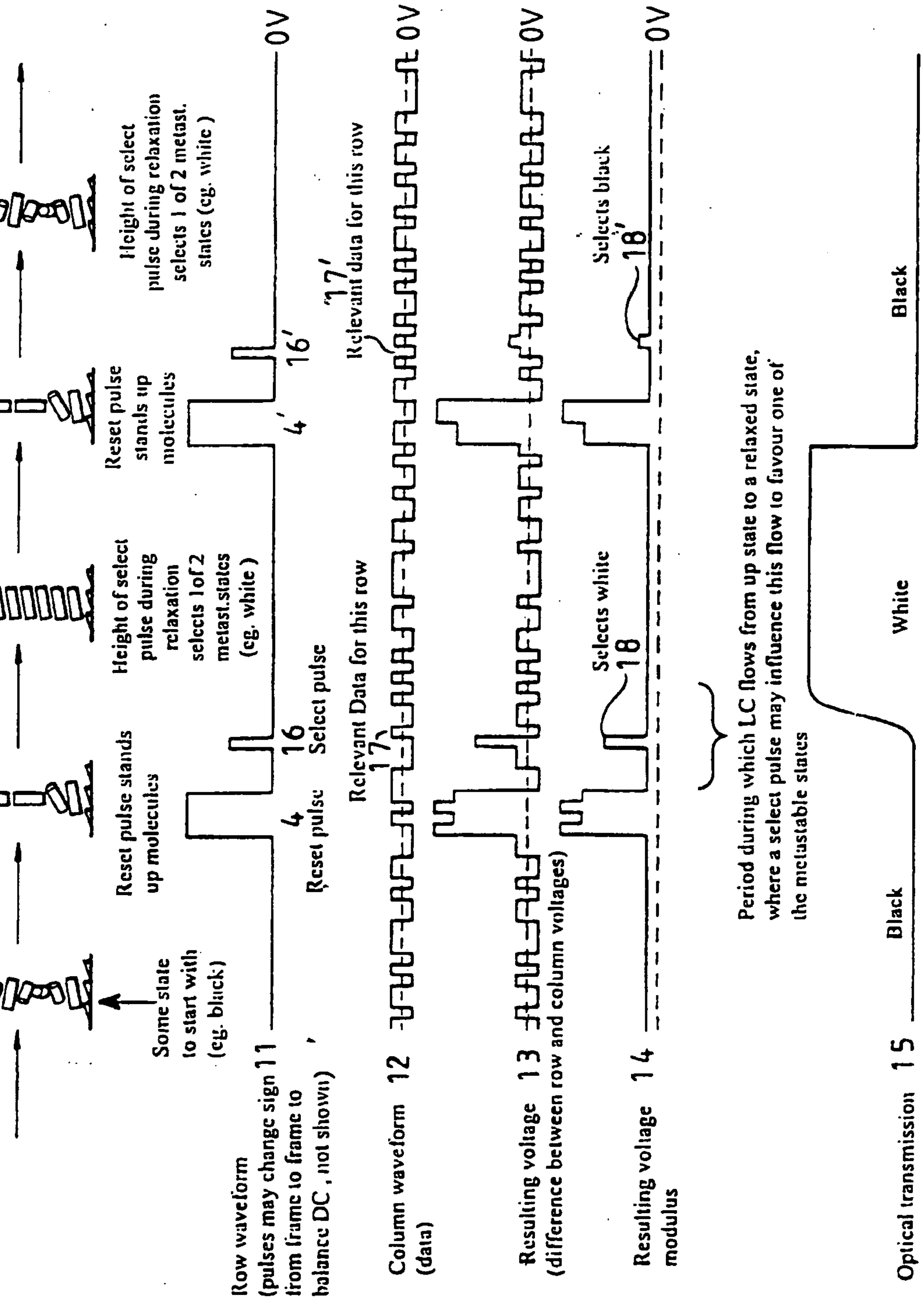

9
6
10
6
9
Some state to start with (eg. black)
Reset pulse stands up molecules
Height of select pulse during relaxation selects 1 of 2 metast. states (eg. white)
Reset pulse stands up molecules
Height of select pulse during relaxation selects 1 of 2 metast. states (eg. white)
Row waveform (pulses may change sign from frame to frame to balance DC, not shown)
11
4
Reset pulse
16
Select pulse
4'
16'
0V
Column waveform (data)
12
Relevant Data for this row
17
17'
Relevant data for this row
0V
Resulting voltage (difference between row and column voltages)
13
0V
Resulting voltage modulus
14
Selects white
18
Selects black
18'
0V
Period during which LC flows from up state to a relaxed state, where a select pulse may influence this flow to favour one of the metastable states
Optical transmission
15
Black
White
Black

FIG 2

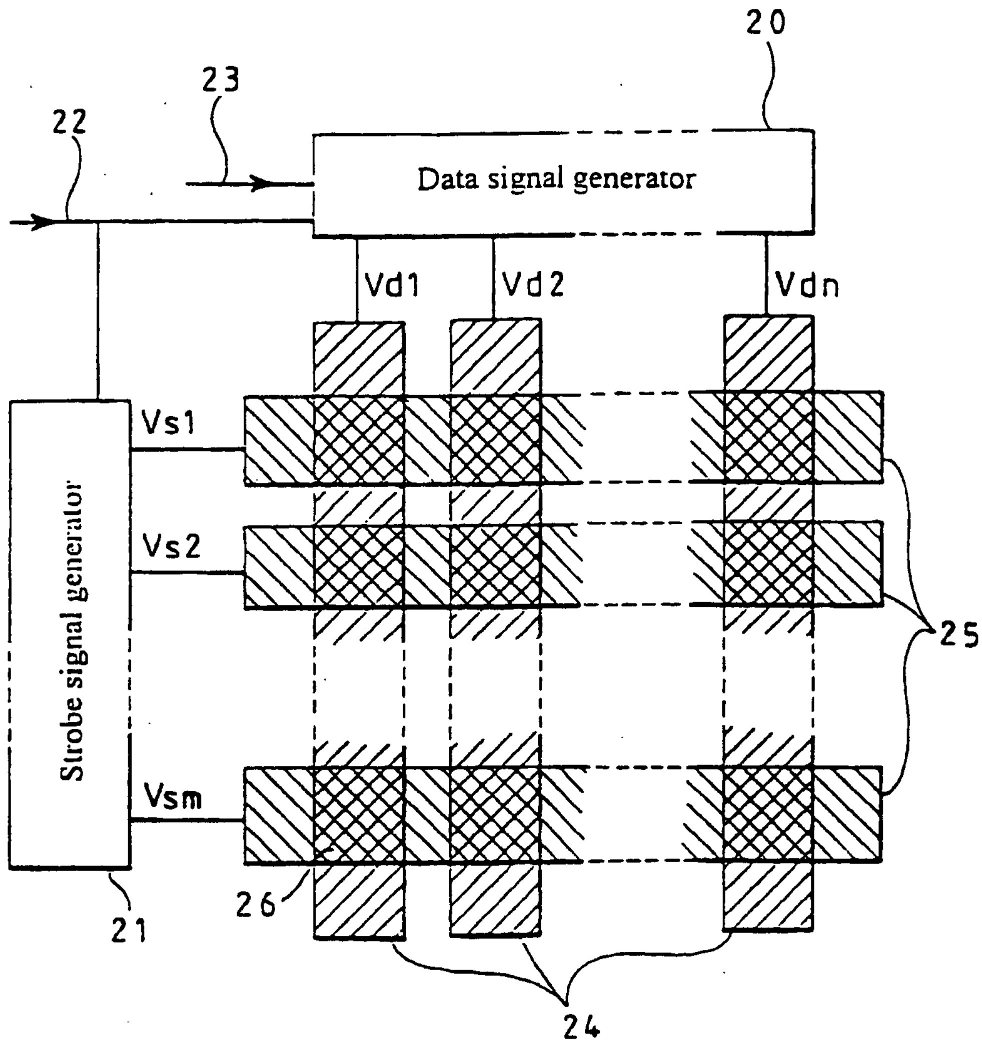

20
23
22
Data signal generator
Vd1
Vd2
Vdn
Vs1
Vs2
Vsm
Strobe signal generator
25
21
26
24

FIG 3

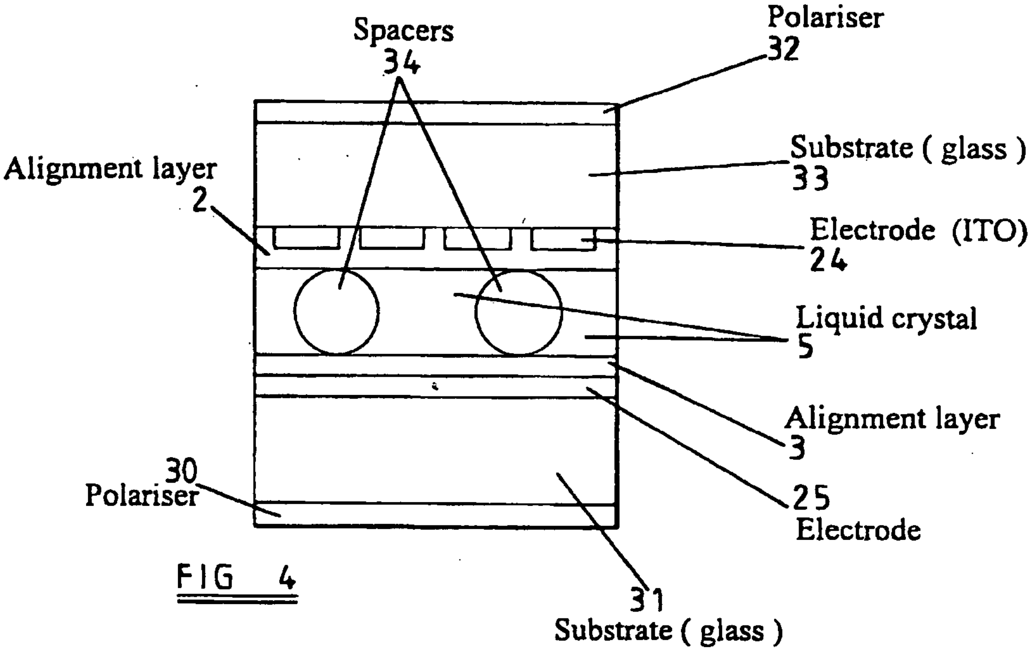

Spacers
34
Polariser
32
Substrate (glass)
33
Alignment layer
2
Electrode (ITO)
24
Liquid crystal
5
Alignment layer
3
30
Polariser
25
Electrode
31
Substrate (glass)

FIG 4

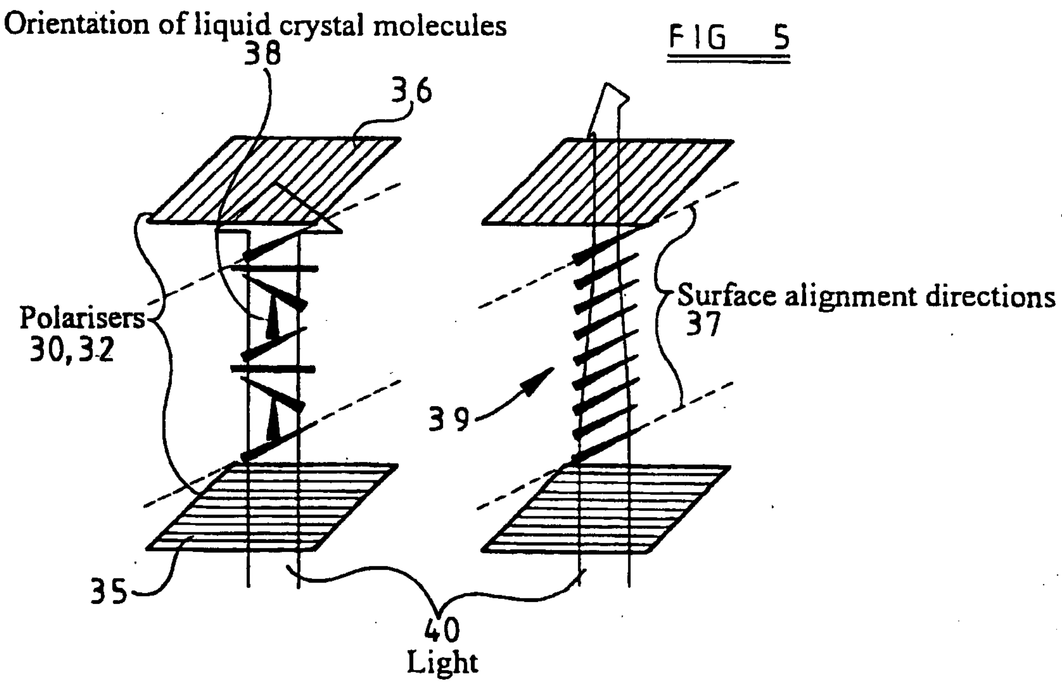

Orientation of liquid crystal molecules
38
36
Polarisers
30,32
Surface alignment directions
37
39
35
40
Light

FIG 5

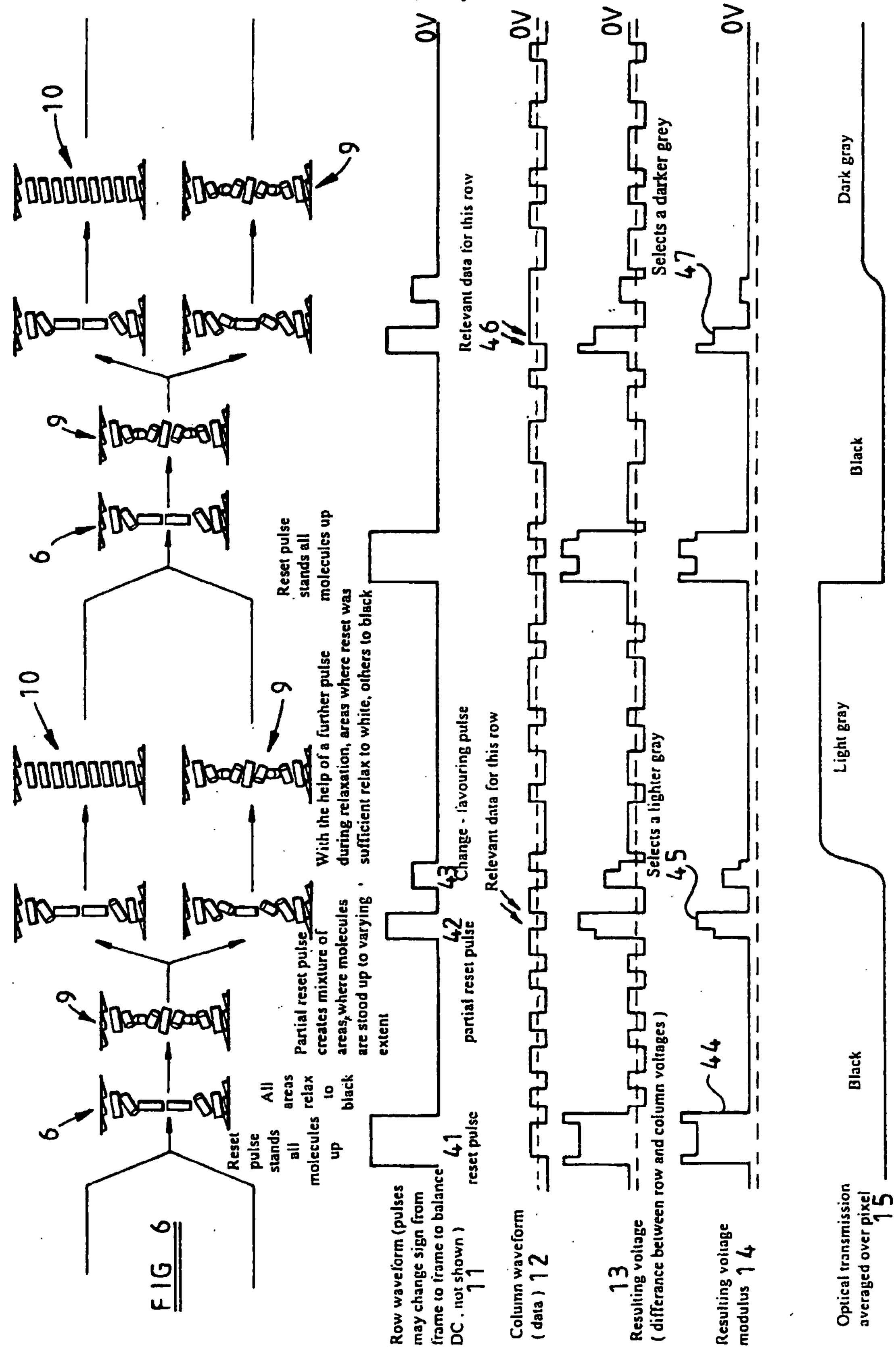

10
9
6
Reset pulse stands all molecules up
All areas relax to black
Partial reset pulse creates mixture of areas, where molecules are stood up to varying extent
With the help of a further pulse during relaxation, areas where reset was sufficient relax to white, others to black
Reset pulse stands all molecules up
0V
41
reset pulse
42
partial reset pulse
43
Change - favouring pulse
Relevant data for this row
46
Relevant data for this row
Selects a lighter gray
45
44
Selects a darker grey
47
Black
Light gray
Black
Dark gray
Row waveform (pulses may change sign from frame to frame to balance DC, not shown)
11
Column waveform (data)
12
13
Resulting voltage (difference between row and column voltages)
Resulting voltage modulus
14
Optical transmission averaged over pixel
15

FIG 6

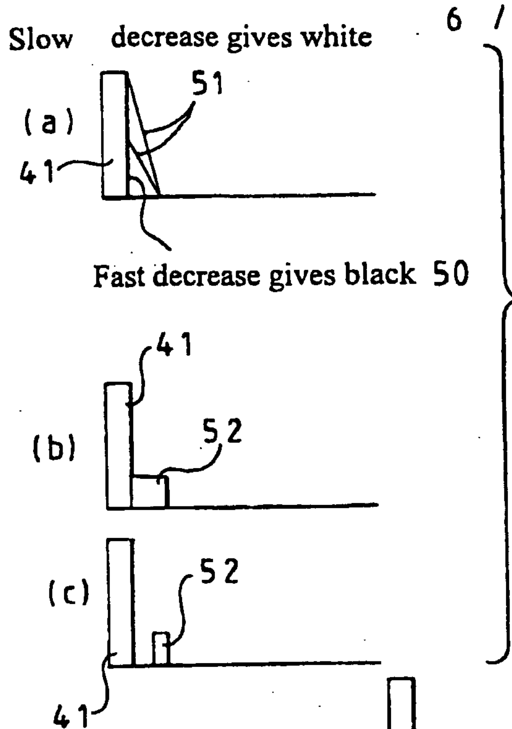

Slow decrease gives white
(a)
51
41
Fast decrease gives black 50
(b)
41
52
(c)
52
41

FIG 7

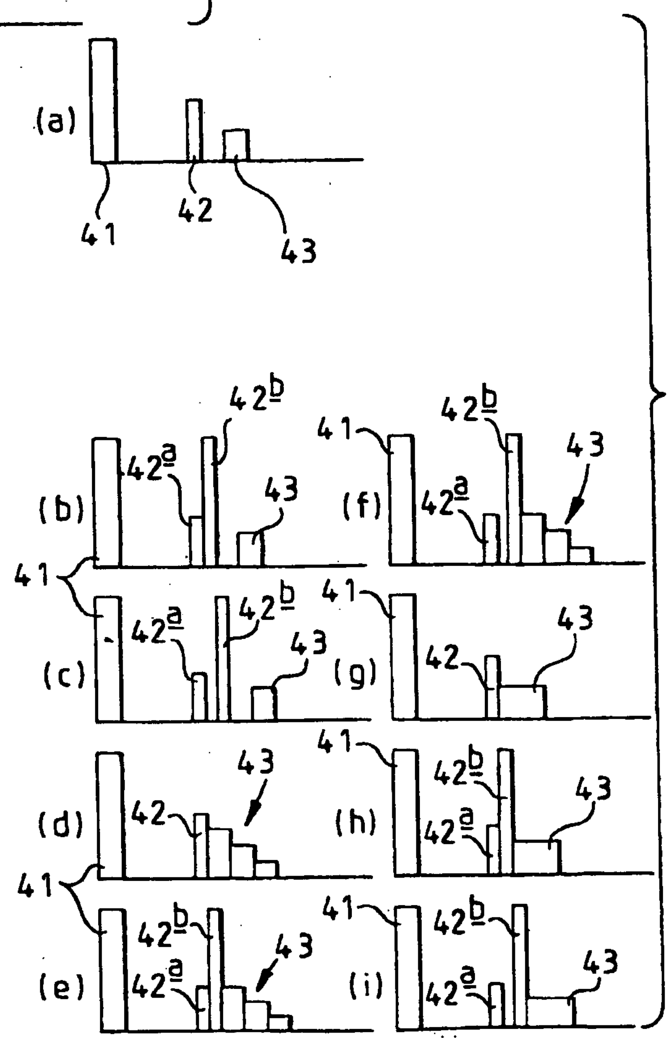

(a)
41
42
43
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
41
42a
42b
42
43

FIG 8

FIG 9

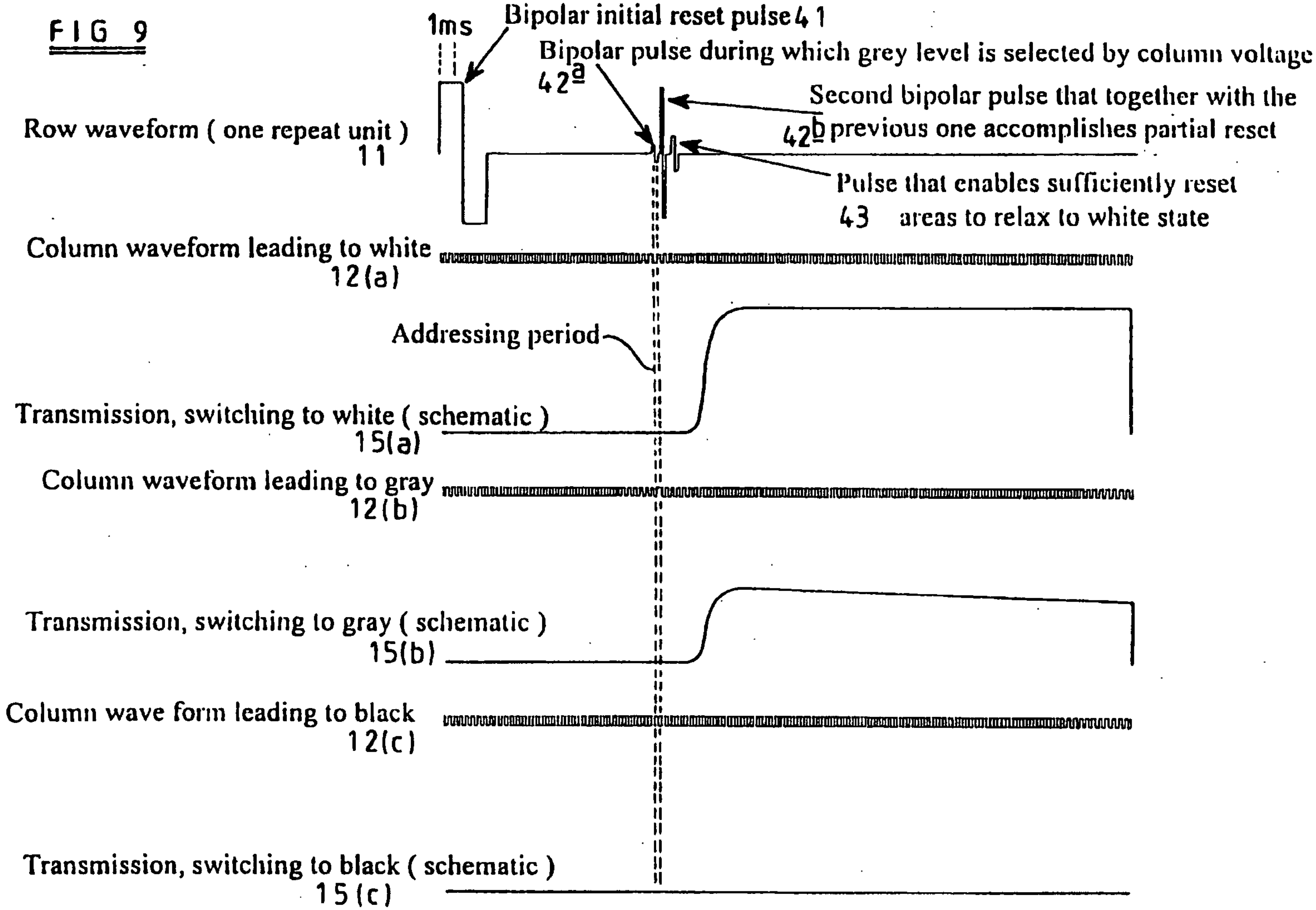
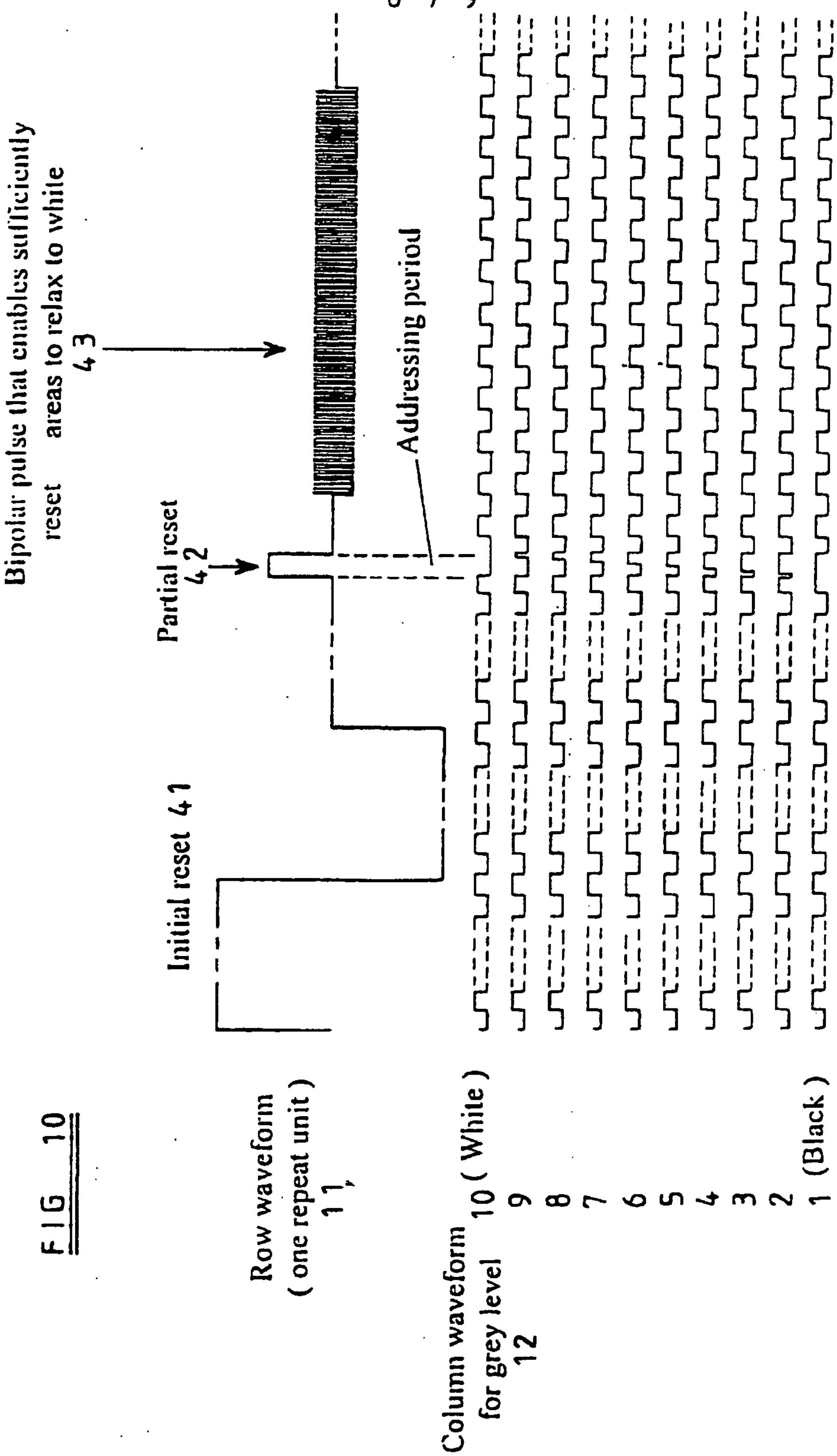
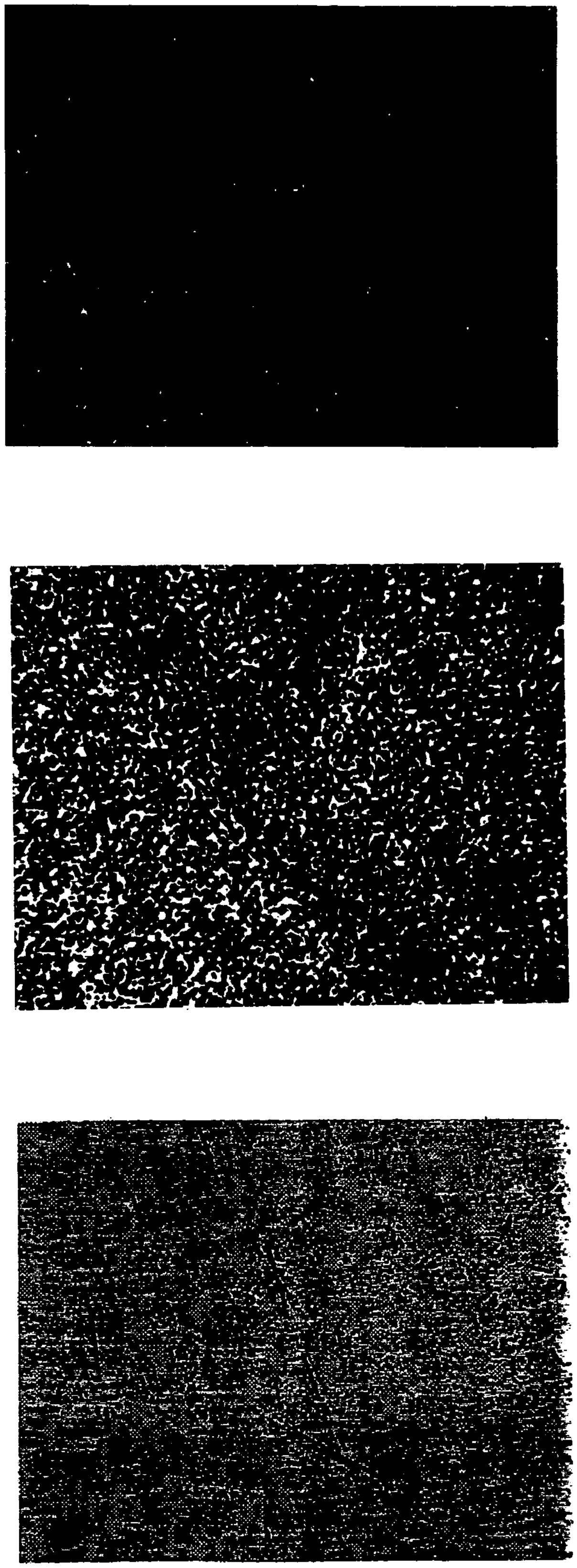

1ms
Bipolar initial reset pulse 41
Bipolar pulse during which grey level is selected by column voltage
42a
Second bipolar pulse that together with the
42b previous one accomplishes partial reset
Pulse that enables sufficiently reset
43 areas to relax to white state
Row waveform (one repeat unit)
11
Column waveform leading to white
12(a)
Addressing period
Transmission, switching to white (schematic)
15(a)
Column waveform leading to gray
12(b)
Transmission, switching to gray (schematic)
15(b)
Column wave form leading to black
12(c)
Transmission, switching to black (schematic)
15(c)

FIG 10


Bipolar pulse that enables sufficiently reset areas to relax to white
43
Partial reset
42
Initial reset 41
Addressing period
Row waveform
(one repeat unit)
11
Column waveform for grey level
12
10 (White)
9
8
7
6
5
4
3
2
1 (Black)



(c)

(b)

(a)

FIG 11

INTERNATIONAL SEARCH REPORT

Inter ›nal Application No
PCT/JP 98/03691

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G09G3/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G09G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 772 067 A (SEIKO EPSON CORP) 7 May 1997 see column 11, line 20 - column 18, line 8; figures 2,3,5-7 ---	1
A	EP 0 569 029 A (SEIKO EPSON CORP) 10 November 1993 cited in the application see column 10, line 5 - column 25, line 4; figures 1-18 ---	1

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 December 1998	04/01/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lerbinger, K

1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/JP 98/03691

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	HOKE C D ET AL: "5.1: MATRIX ADDRESSING OF A 0 -360 BISTABLE TWIST CELL" 1997 SID INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS, BOSTON, MAY 13 - 15, 1997, no. VOL. 28, 13 May 1997, pages 29-32, XP000722651 SOCIETY FOR INFORMATION DISPLAY see the whole document	1
A	BERREMAN D W ET AL: "NEW BISTABLE LIQUID-CRYSTAL TWIST CELL" JOURNAL OF APPLIED PHYSICS, vol. 52, no. 4, 1 April 1981, pages 3032-3039, XP002009196 cited in the application see page 3038, right-hand column - page 3039, left-hand column	1

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/JP 98/03691

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0772067 A	07-05-1997	CN 1152962 A	25-06-1997
		WO 9636902 A	21-11-1996
EP 0569029 A	10-11-1993	DE 69318062 D	28-05-1998
		DE 69318062 T	01-10-1998
		JP 6230751 A	19-08-1994
		US 5594464 A	14-01-1997